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Biogenic/Abiogenic Hydrocarbons' Origin

Possible Role of Tectonically Active Belts

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Extended Abstract

Introduction. It is nearly obvious that the creation of hydrocarbons is linked to tectono-geologic processes and particularly to orogenesis. Rifting, overthrusts, erosion, deposition of sediments, deep gas emissions, etc. all can contribute to the burial and to the metamorphosis of biogenic and/or abiogenic materials into hydrocarbons. But this connection with orogenesis should be expected to be different in the case of different gobal tectonic theories. Indeed, isolated voices have claimed the inadequacy of plate tectonics in linearly explain a number of phenomena involved in hydrocarbons generation (Pratsch, 1978) and geological processes (Hilgenberg, 1974; Carey, 1975; Chudinov, 2001, part 3, on ore deposits; Scalera, 2006, 2007ab,2008).

The second major font of debates is the biogenic or abiogenic origin of petroleum, or eventually the possibility of a mixing of the two generation processes. While the organic origin hypothesis was traditionally followed in the western world, successful predictive procedures based on abiogenic origin have been developed by geoscientists of the former Soviet Union. Progressively more numerous there are becoming the evidence supporting the abiogenic origin of many compounds that are found in the oil reservoirs and elsewhere (Horita & Berndt, 1999; Sherwood Lollar et al., 2006; Sherwood Lollar et al., 2008; Fiebig et al., 2004; Fiebig et al., 2007; and many others), and today it is admitted that some oil fields are of abiogenic nature. Then, the co-presence of both biogenic and abiogenic signatures in various rates in most hydrocarbons fields should be considered an important clue in defining new models of gas and oil formation. In this short note I will try to assess the possibility of a recently proposed model of fold belt evolution to be in agreement – and in what limits – with the observed phenomena.

Biogenic and abiogenic field evidence. The biogenic theory is corroborated by many biomarkers (e.g. oleanane linked to angiosperms) with undoubted link to the flora that existed in that geologic epoch (Mello & Moldowan, 2005) and to the actual deposition into sediments of air dispersed organic volatile materials or buried plants (Brooks, 1948; Hobson & Tiratsoo, 1975; among others) and remnants of animal life. Many types of oils are indicative of a rapid deposition of the organic source material into subsiding basins, and this is in accord with geologic evidence. Evidence are also clear that a number of complex substances in the petroleum have a thermo-labile behaviour and never experienced

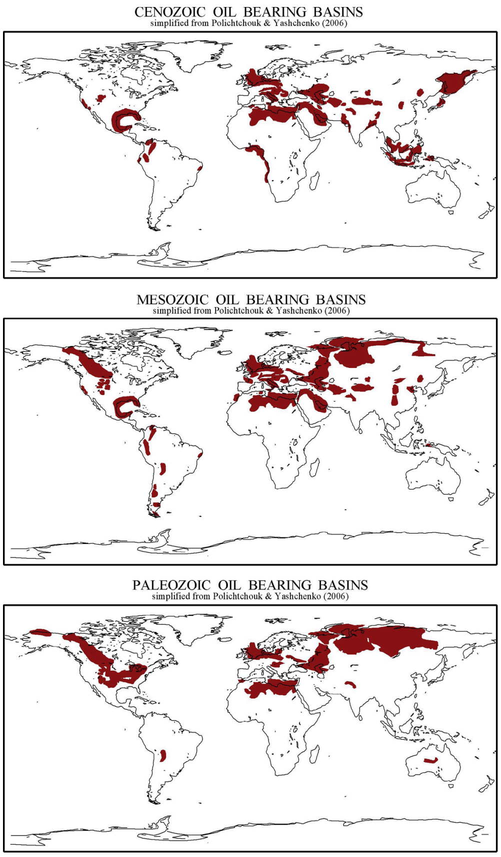

Fig. 1. The relation between the distribution of hydrocarbons and their age. Upper Map: Distribution of Cenozoic oil-bearing basins. Central Map: Distribution of Mesozoic oil-bearing basins. Lower Map: Distribution of Palaeozoic oil-bearing basins. Redrawn and simplified from Polichtchouk & Yashchenko, 2006.

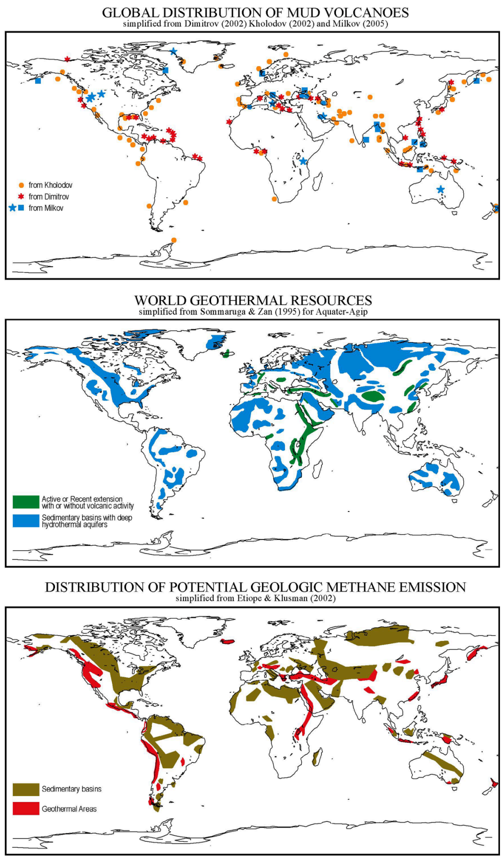

Fig. 2. The relation among the distribution of hydrocarbons and others tectonically related features. Upper Map: Distribution of mud volcanoes, drawn integrating maps of Dimitrov (2002), Kholodov (2002), Milkov (2005). Middle Map: Geothermal resources of the world, redrawn and simplified from Summaruga & Zan (1995), in which recent rifting and hydrothermal aquifers are shown. Lower Map: Potential geologic methane emission regions, redrawn from Etiope & Klusman (2002). Mud volcanoes have a god fit with the Cenozoic Oil Bearing Basin. This is clue that where mud volcanoes are present but no oil fields are mapped the region should be better explored (e.g. the southern tip of India). Low energy geothermal aquifers (blu areas in Sommaruga & Zan) can be associated to oil field, while the high energy Recent extensional regions (green areas in Sommaruga & Zan and red areas in Etiope & Klusman) generally are not concomitant with oil. This evidence is in agreement to the new proposed model because the initial extensional phases cannot produce deep or shallow suitable condition to hydrocarbons formation.

high temperatures. The depletion of ^{13}C in the oil fields and in diamondoids is considered a further evidence because the chlorophyll cycle favour the retention of ^{12}C (but different explanations are possible).

Some isotopic markers are of clear abiogenic origin, and especially the presence of Helium witness for a deep origin of the material flux. Some enrichment and depletion in isotopic species are also considered clues of a deep and then abiogenic origin.

Szatmari (1989) proposed that the Fischer-Tropsch well known industrial process of synthetic oil production is the actual chain of chemical reaction occurring in the geological environment. It needs that - with the catalyst action of the iron (in magnetite and hematite) - CO_2 or CO is reduced by an idrogen flux generated by serpentinization of lithosphere and subduced ophiolite.

Many findings of abiogenic methane and HCs have been reported in association to serpentinised rocks (Szatmari et al., 2005; Sachan et al., 2007) and other geological environments (Horita & Berndt, 1999; Sherwood Lollar et al., 2006; Sherwood Lollar et al., 2008; Fiebig et al., 2004; Fiebig et al., 2007). Experimental evidence that HCs can be naturally produced by abiotic chemical reactions is growing (Scott et al., 2004; Martinelli & Plescia, 2005).

The old and main critique (frequently discussed starting from the second half of 19th century; Brooks, 1948) of the followers of inorganic origin of petroleum is that the temperatures evaluated from the geologic history of many reservoirs was not sufficient to the process of oil distillation envisaged by the first biogenic conceptions. Many other arguments and factual data about abiogenic origin can be found in Hedberg (1969), Porfir'ev (1974), Glasby (2006), Katz et al. (2008).

Many others worked adopting the abiogenic conceptions and Szatmari (1989) proposed that the industrially adopted Fischer-Tropsch synthesis of artificial oil could also occur in upper lithosphere. The needed high temperature and the too oxidizing state of upper mantle is a serious problem for the validity of the Szatmaris idea. This criticism has been recognised by Kenney et al. (no date) who has proposed what is considered the modern version of the abiogenic framework (Kenney et al., 2002). In their conceptions, the hydrocarbons are formed from abiogenic methane, but this is possible – because of the constrains of the law of thermodynamics – only to pressures greater than 30 kbar (depth >100 km) and temperatures > 700°C. If the environment is oxidizing – as it is in the upper part of the upper mantle, the impossibility to transform carbonates or/and the organic remains of plants (carbohydrates) into hydrocarbons and oil follows from thermodynamics (Kenney et al., 2002).

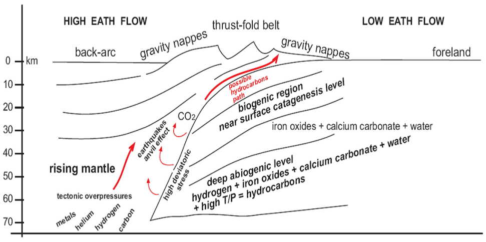

Fig. 3. The connection between the proposed model (Scalera, 2007b, 2008, 2010) and various kind of hydrocarbons generation. The convergence of cold and hot materials, oxidizind and reducing environments, the presence of high nonlithostatic overpressures, and ascending fluids and catalysts, constitute a favourable dynamical environment in which different types of metamorphism can be realized at shallower depth, ore deposits can form near the surface and the synthesis of biogenic and abiogenic hydrocarbons can occur at depths not exceeding few tens of kilometres.

Possible new armonic scenario of the hydrocarbons formation. Oil and associated phenomena can be found preferentially along old fold belts and margins (Fig. 1 and 2) which building models can be very different in different global tectonics theories. The fold belt building model proposed in preceding papers by Scalera (2007b, 2008, 2010) can be used to judge if the several difficulties encountered by the different biogenic/abiogenic conceptions can be solved (Fig.3). In Fig.3 the main characteristics of the model are shown in connection to the abiogenic/biogenic oil production problems.

The tectonic overpressures (Mancktelow, 1995; Mancktelow & Gerya, 2008), together with the higher temperatures available in the model of Scalera (2007b, 2008, 2010) at shallower depth, can bear a relation with the synthesis of biogenic and abiogenic hydrocarbons. Indeed Glasby et al. (1984) argued that most HCs fields occurs in areas of higher than normal thermal gradient, and the above proposed model lead just to higher gradients that are produced by the isostatic uplift of very deep materials (from and above the transition zone). These higher gradients together with uplifted contents of mantle metals (catalysts) and hydrogen, can favour the occurrence of the conditions leading to the development of the Fischer-Tropsch reaction. The underthrust carbonate slabs – formerly produced in the basin-rift phase – can interact at proper high temperature with hydrogen and catalityc metals. Pressure range can be very wide both because the nonlithostatic overpressures (Mancktelow, 1995; Mancktelow & Gerya, 2008) at the boundary between uplifting material and adjacent stable or underthrust lithosphere and occasionally because the inevitable occurrence of strong earthquakes (to be also considered a further supply of energy) in some periods of the thrust-fold belts building (Fig. 3 and 4). Laboratory experiments (Martinelli & Plescia, 2005) have recently ascertained that calcareous-marly rocks to which friction is applied produce a strong emission of carbon dioxide and methane of inorganic origin.

The compressional state of the gravity-driven nappes, together with the general rifting environment of the proposed model and the aperiodic activation of deep change of phase with extrusion of material below the fold belt, can be a substantial facilitating factor in oil migration towards the surface and its accumulation under impermeable layers, following the slopes of the underthrust strata. A surfaceward uplift of deep materials needs, with an associated lithospheric fracturing provided by a rifting and/or thrust-fold belt building, to trigger, additionally, the Fischer-Tropsch reaction.

The recurrent criticism (Glasby, 2006) of the lack of reducing condition in the upper part of the upper mantle to be possible the Fischer-Tropsch reaction, is then overcome in this model by the upwards isostatic transport of the reducing transition zone environment (Fig. 3). Also the criticism of Kenney that the suitable TP conditions to produce HCs can be found only at depth greater than 100 km is overcome by the transport of such conditions toward the surface (Fig. 3).

While in plate tectonics the cold slab travels in contact with the lithosphere of the continental side, oxidizing materials faced to oxidizing materials, in my framework a high-temperature reducing environment of undepleted mantle rises up and come in contact with the relatively cold oxidizing lithospheric environment. It is easy to cheek that in the interposed region of thermal gradient, and of hydraulic gradient due to non lithostatic overpressures (Mancktelow, 1995; Mancktelow & Gerya, 2008) – all at depths not overcoming few tens of km – a continuum of very different physicochemical conditions come in existence. A number of chemical reaction are then favoured in this sort of tectonic oxidizing-reducing pile, leading to a multiple origin of hydrocarbons. However, no evaluation of the abiogenic/biogenic hydrocarbons rate is yet possible.

In addition, near to the surface – in the first few tens of kilometres – a considerable amount of fluids (Fyfe, 1978) and of organic biogenic material of various provenance is present in the underthrust sedimentary layers, which can participate in a passive way (contaminant) or active way (transmuting materials, kerogens) to the HCs forming.

We should expect that an asymmetry in the amount and distribution of the HCs fields should result crossing an active margin. The cold side of these regions (e.g. the continental side of the Apennines, the Andes, etc.) should be more suitable for petroleum exploration, because the squeezing of fluids caused occasionally by the aperiodic overpressures towards the decreasing horizontal hydraulic gradient. The horizontal flow toward the warm side should with great probability disintegrate the heavy HCs molecules, while they should conserve integrity going toward the cold region. It should be a matter of on-field experiments (drillings) to test if HCs are accumulated under the axial zone of the thrust-fold belts.

The Italian scenario of the hydrocarbons formation. A comparison of the Italian hydrocarbon fields with some major geophysical-geological features of the Italian region (see in Fig.5 the volcanic, seismic, gravimetric, magnetic features) is useful to roughly test the model. A simple comparison of the petroleum and gas fields (data from Pieri, 2001) with the maximum felt intensity (VIII, XI, X and XI MCS degrees) shows a initial good agreement of the model and the highest seismic energy

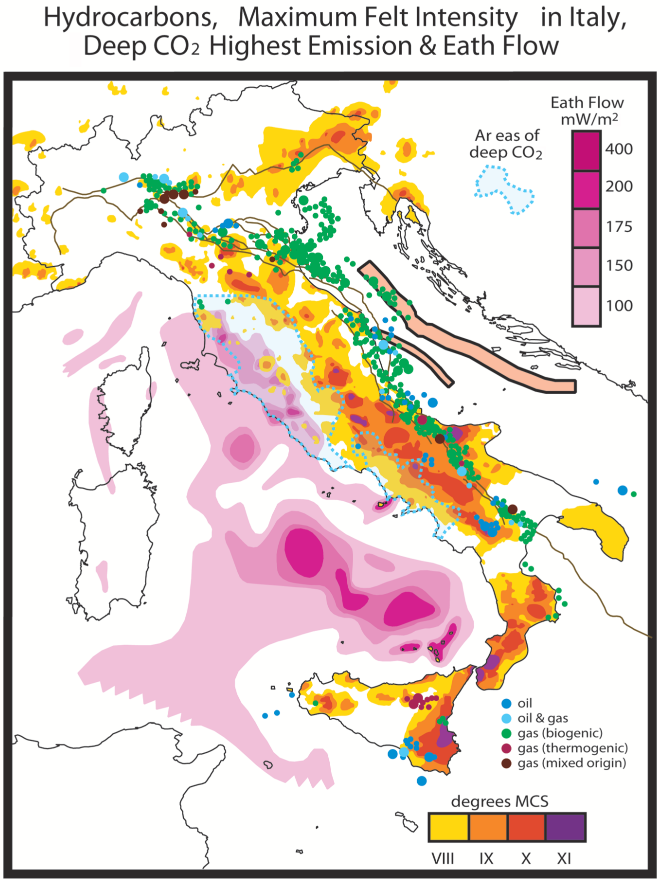

Fig. 4. The data of locations and productivity of hydrocarbon fields in Italy are from Pieri (2001). The maps of the MCS degrees from VIII to XI is extracted from the Maximum Felt Intensity in Italy that was elaborated by INGV (Boschi et alii, 1995). The front of the orogen is also shown (from Bigi et alii, 1991). The hydrocarbons are located beside the eastern side of the highest seismic energy releases. The further adding to this map of the zones of heat flow greater than 100 mW/m^2 (redrawn from the map by Della Vedova et alii, 1991) shows that a similar warm/cold zonation exists like the one proposed in the model (Fig.3). Highest CO_2 emissions (Chiodini et al., 2004) can be of mantle origin or can be produced by the margin of the underthrust carbonatic platform with the help of the earthquakes. Adjacent to the eastern side of the higher degree seismicity, and following the Adriatic plate margin (revealed by a long magnetic anomaly), the hydrocarbons has been found in commercial quantities. They can mostly or partially came from the chemical reactions envisaged in this paper, and then pushed toward east by hydraulic gradients and favorable disposition of microfractures and impermeable sedimentary layers. The two flesh ribbons in the Adriatic sea represent main seismogenic faults (Basili et al., 2009) along which new HC fields may be found.

release. The earthquakes seems to enclose an elongated area of tectonic working in which hydrocarbons can be produced in the depts. and then expelled laterally toward the cold side of the region. The 'warm side' can be considered the region where the volcanic rocks and the seismicity highest-degree seismicity are located (Fig. 4 and 5). On this side HCs cannot migrate without be disintegrated. The oil and gas could benefit of the same mechanical ac-

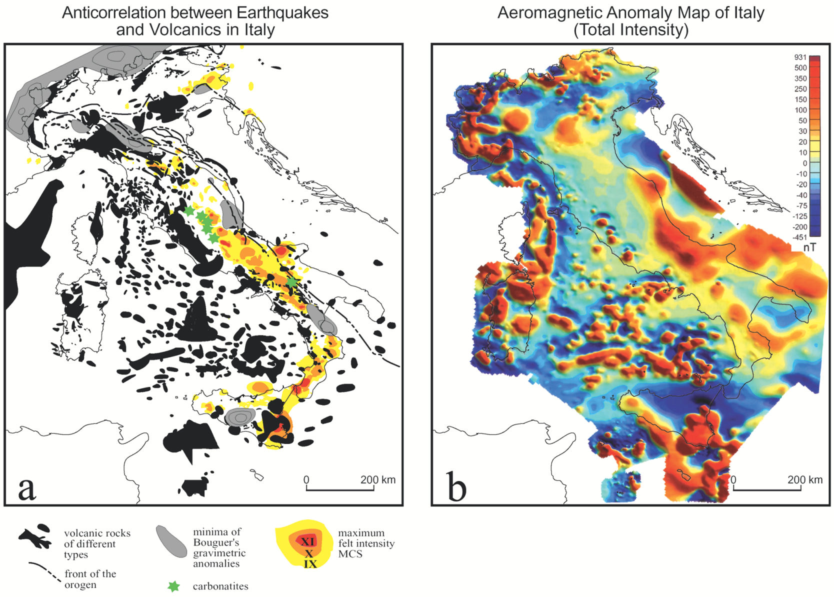

Fig. 5. In a) a comparison is shown between the higher values of the maximum felt intensity (IX, X, XI MCS degree) (Boschi et al., 1995) and all the volcanics (black areas) that are reported in "Structural Kinematic Map of Italy" (Bigi et al., 1991), in "Magnetized Intrasedimentary Bodies" (Cassano et al., 1986), and in Lavecchia & Stoppa (1996, carbonatites). The more energetic Apenninic seismicity is confined in the gaps of volcanics, and mainly immediately west from the orogen front. Recently discovered carbonatites (green stars) help to better define the anticorrelation between volcanics and earthquakes. Another factor of inhibition of seismicity is the presence of minima of the Bouguer gravimetric anomaly, which are related to greater crustal thickness and/or to different characteristics of the crust. In b) a long alignment of large positive magnetic anomalies is recognizable in the total intensity map (Caratori Tontini et al., 2004) from Ancona to Calabria (similar result, although higher frequencies are shown, in the map of Chiappini et al., 2000), which seems to delimitate the western boundary of the Adriatic lithosphere, where phenomena of extrusion of the magnetic basement are possible (Speranza & Chiappini, 2002).

tion of the high stress indicated by the earthquakes in creating microfractures (before their coalescence in a bigger fault; see Crampin, 1999), through which these fluids can migrate towards oil fields or the surface. This migration can become true expulsion with local firing during a seismic event. In Fig.5b (from Caratori Tontini et al., 2004) the magnetic anomaly elongated from Ancona to Calabria is nearly coincident with the oil-gas fields pattern and is the indication of the western edge of the Adriatic plate.

Albeit the pattern of the oil fields does not reflect exactly the real oil-gas distribution – in the sense of a possible wider and different distribution if numerous new finding will be discovered – the actual situation seems in accord to the proposed model in which an important role should have the abiogenic hydrocarbons in particular those produced by the tectonic working at the western margin of the Adriatic plate. Deeper investigations and analyses need in determining the the real rate (biogenic/abiogenic) of the Italian hydrocarbons.

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